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ONSHORE TREATMENT SYSTEM FOR SEWAGE FROM WATERCRAFT RETENTION SYSTEMS

A. J. Glueckert, et al

General American Transportation Corporation

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REVIEW NOTICE

The National Environmental Research Center -- Cincinnati has reviewed this report and approved its publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise, and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment--air, water, and land. The National Environmental Research Centers provide this multidisciplinary focus through programs engaged in

- studies on the effects of environmental contaminants on man and the biosphere, and
- a search for ways to prevent contamination and to recycle valuable resources.

The appreciable growth of recreational activity in this country has presented an additional burden on our land and water resources. Recreational watercraft waste is a minor fraction of the waste flow from landbased sources. Their presence, however, in our environment contributes to the total ecological problem we face today and demands that we develop waste treatment solutions that are technically and economically feasible.

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Director
National Environmental
Research Center, Cincinnati

ABSTRACT

During this program an evaporative waste treatment system for onshore treatment of sewage from watercraft retention systems was developed and demonstrated. Wastes and chemical additives associated with recreational watercraft holding tanks were characterized by analyses of sewage samples obtained from marina and watercraft retention tanks utilizing both freshwater and seawater flushed sanitary systems and by a survey of typical chemical additives employed as bacteriostatic and odor reducing agents. An evaporative waste treatment system was evaluated by testing a propane-fired evaporator for 224 hours with in-house sewer wastes and wastes collected from marina holding tanks. The evaporative system treated 4,590 liters (1,212 gal.) of sewage and concentrated the total solids of the sludge from the initial 0.5% to 12.4% before servicing and removal of the concentrated sludge was required. Because the chemical additives of holding tanks caused foaming, the evaporator had to be operated at approximately 50% of its capacity; however, additives had no other deleterious effects on the evaporative system. The concentrated sludge produced in the evaporator was incinerated in a batch-type incinerator. Although the incineration of the sludge was feasible, the available incinerator was too small to handle all the sludge which could be produced by the continuously operating evaporator. Continuous operation of the evaporator requires approximately 1.0×10^6 kilocalories per 1000 liters of wastewater evaporated (15×10^6 Btu/1000 gal.); the actual costs depend on the fuel used and its price.

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SECTION I

CONCLUSIONS

The concept of concentration of watercraft sanitary wastes through evaporation was demonstrated. The solids concentration of the wastes was increased from 5 percent to 12.4 percent by weight. This appears to be the upper limit of waste concentration in an evaporative process. Higher concentration sludges are difficult to remove from the evaporator by pumping and impede heat transfer from the evaporator steam jacket to the wastes.

Chemical additives had no deleterious effect on the evaporator, except some caused severe foaming during boiling. This foaming can be controlled by (1) addition of antifoam emulsions, (2) increasing the evaporator height to allow more ullage, and (3) decreasing the rate of heat input.

The use of an incinerator that would burn the sludge from the evaporator was investigated; however, the capacity of the incinerator was only a fraction of that required to process the sludge from a 950 l/day (250 gal./day) evaporator. Also, the trays that contain the sludge in the combustion chamber had a relatively short life because of the hot corrosive environment to which they were exposed.

No commercially available incinerator was found in the size required for handling sludge from the 950 l/day (250 gal./day) evaporator.

The capital costs for an evaporative system capable of treating 1900 liters/day (500 gal./day) of sewage, including ancillary equipment and a catalytic vapor treatment system, are approximately $20,000. The evaporator requires approximately 1.0×10^6 kcalories per 1000 liters of sewage processed (15×10^6 Btu/1000 gal.); the actual operating costs depend on the fuel used.

SECTION II

RECOMMENDATIONS

Since the evaporator demonstrated the ability to concentrate sanitary wastes from marina holding tanks, it should be tested in the field at a marina site with the following modifications: (1) increase the ullage height to handle foam, (2) substitute a macerator pump for the present feed pump to grind all solid wastes, and (3) add a vapor treatment system to eliminate stack odors.

In order to make the evaporator applicable in areas where the sludge cannot be used for land fill, the present incinerator should be enlarged to handle the sludge produced by a 950 l/day (250 gal./day) evaporator. This would entail enlarging the combustion chamber to handle larger trays.

Also, the tray material study should be pursued further to maximize the service life of the trays.

SECTION III

INTRODUCTION

GENERAL

To comply with the no-discharge requirements, sanitary wastes produced on small recreational watercraft must be retained onboard in recirculating/retention waste systems. Chemical additives are commonly used to suppress the activity of bacteria and to control the odor. Wastes from the holding tanks of individual watercraft are generally pumped out to on-shore storage tanks at marinas.

The acceptable method of disposal of sanitary wastes collected from watercraft at marina pumpout stations presents a difficult problem. Wastes collected from holding tanks of watercraft are generally more concentrated than typical wastes entering municipal sewage treating plants and contain relatively high concentrations of chemical additives that may upset conventional biological sewage treatment systems if flushed into sewers without adequate dilution. Besides, many marinas are located far from any connection to municipal sewers and sewage treatment plants. The marina pumpout station operator then must have these wastes hauled to a possible suitable disposal site.

The General American Research Division (GARD) of the General American Transportation Corporation (GATX) has developed an Evaporative Toilet System (ETS)* for the collection and treatment of raw sewage. The system was specifically designed for those applications where a direct disposal of toilet wastes into normal sewage systems is impossible and/or impractical. The GATX Evaporative Toilet System concentrates the collected raw toilet wastes by boiling off the water. This reduces the total volume of the retained sludge and increases the service interval of the collection/evaporation tank. In practice, the volume of the sludge can be reduced to approximately 1/15 of the

* U.S. Patent No. 3,787,901

original sewage volume before servicing and removal of the concentrated sludge becomes necessary. An additional advantage of the system is that both the boiled-off steam and the remaining sludge concentrate are rendered sterile, and therefore, are biologically safe to handle.

This report describes the application of the evaporative system to the concentration of watercraft sanitary wastes collected at marina pumpout stations to produce sludge that can be burned in an incinerator or, being sterile, dried and used for landfill, as an alternative to hauling the wastes to municipal sewers or other disposal sites.

OBJECTIVE

The objective of this program was to develop an onshore sanitary treatment system which is capable of processing 1900 liters (500 gal.) per day of sewage from watercraft waste retention systems.

SCOPE

The investigation of an onshore sanitary treatment system performed under this program included: (1) the determination of waste characteristics from watercraft retention tanks, (2) a survey of chemical additives used in the tanks, (3) an adaptation of the evaporative waste treatment system for use with sewage from watercraft retention systems and laboratory testing of the evaporator, and (4) adaptation and laboratory testing of an available incinerator.

SECTION IV

CHARACTERISTICS OF WASTES

Marinas located on both sea coasts, the Great Lakes, and U. S. National Park Service recreational areas were contacted to find out how watercraft sewage holding tanks were serviced. Where possible, samples of pumpout wastes were collected and analyzed.

MARINAS

Table 1 summarizes information about the marinas contacted.

SAMPLE SOURCES

Twelve samples were obtained for analysis. The source of each sample is described below:

Sample 1 was taken from Marina Del Ray in Del Ray, California. This sample was taken directly from a Raritan Crown Deep Draft toilet with a nonrecirculating holding tank having a capacity of 440 l (115 gal.) and using Raritan antipollution concentrate as a bacteriostatic agent. This toilet uses seawater for flushing.

Sample 2 was obtained from Marina Del Ray in Del Ray, California. This sample was taken directly from a Raritan Compact toilet with a recirculating holding tank having a capacity of 27 l (7 gal.) and using Kem-Klear as a bacteriostat. This toilet uses freshwater for flushing.

Sample 3 was obtained from a U.S. National Park Service freshwater marina pumpout station located at Callville Bay, Lake Mead, Arizona.

Sample 4 was obtained from a U.S. National Park Service freshwater marina pumpout station located at Las Vegas Bay, Lake Mead, Arizona. This sample contained an excessive amount of oil, and, as a result, no representative samples could be analyzed.

Table 1. MARINA FACILITIES

Marina	Location	Pumpout Capacity
1 Larsen Marine	Waukegan, Ill.	1900 l (500 gal.) tank plus 3800 l (1000 gal.) tank
2 Chicago Park District (Lake Michigan harbors)	Chicago, Ill.	Direct to sewers and 3800 l (1000 gal.) tank
3 Marina Del Ray	Del Ray, Calif.	Direct to sewers
4 Palmer Johnson	Racine, Wis.	950 l (250 gal.) tank
5 Snug Harbor	New Buffalo, Mich.	3800 l (1000 gal.) tank plus 380 l (100 gal.) portable tank
6 Washington Park	Michigan City, Ind.	210 l (55 gal.) portable tank
7 Abbey	Lake Geneva, Wis.	Direct to sewers
8 Joliet Yacht Club	Joliet, Ill.	1001 l (275 gal.) tank
9 Pugh's Peerless Marina	Racine, Wis.	210 l (55 gal.) portable tank
10 U.S. Nat'l Park Service	Lake Mead, Ariz.	---
11 Pier 66 Marina	Ft. Lauderdale, Fla.	Direct to sewers

Sample 5 was obtained from Belmont Harbor in Chicago, Illinois. This sample was taken from an underground holding tank having a capacity of 7500 l (2,000 gal.). The harbor maintains mooring facilities for 350 boats.

Sample 6 was obtained from Larsen Marine Service in Waukegan, Illinois. This sample was taken directly from an underground holding tank having a capacity of 1900 l (500 gal.). The marina maintains docking facilities for 200 boats.

Sample 7 was also obtained from Larsen Marine Service in Waukegan, Illinois. This sample was taken directly from a portable holding tank having a capacity of 210 l (55 gal.).

Sample 8 was obtained from Palmer Johnson Marina in Racine, Wisconsin. The sample was taken from an aboveground holding tank having a capacity of 950 l (250 gal.). The marina maintains mooring facilities for 70 boats.

Sample 9 was obtained from Pugh's Peerless Marina in Racine, Wisconsin. This sample was taken directly from a 210-l (55-gal.) capacity portable holding tank. The wastes are pumped from the holding tank directly into the city sewer system. The marina maintains mooring facilities for 75 boats.

Sample 10 was obtained from Marina Del Ray directly from a Raritan Crown Deep Draft Toilet with a nonrecirculating holding tank having a capacity of 440 l (115 gal.) and using Raritan antipollution concentrate as a bacteriostat. Seawater was used for flushing; this is similar to Sample 1.

Sample 11 was obtained from Marina Del Ray from a Monogram Classic system with a 280-l (75-gal.) holding tank using a Jabsco macerating pump and standard Lysol as a bacteriostat. Again, seawater was used for flushing.

Sample 12 is a composite from six 210-l (55-gal.) drums of wastes collected by a "honeywagon" operator who services construction sites and marinas in the Chain-O-Lakes area of northern Illinois.

SAMPLE ANALYSIS

The waste samples were analyzed according to the methods shown in Appendix A; the results of the analyses are summarized in Table 2. Sample 10 was reported to be from a saltwater flush system; however, this is questionable because the total solids of a seawater flushed system should be greater than 3.5 percent, the solids concentration of seawater.

As expected, samples from toilets using a seawater flush system (Samples 1, 6, and maybe 10) showed a higher chloride content and higher conductivity than samples from toilets using freshwater flush. Heavy metal concentration was

Table 2. WASTE CHARACTERISTICS

Characteristic	Sample*											Range
	I	II	III	V	VI	VII	VIII	IX	X	XI	XII	
1. Total Solids, wt percent	4.17	1.93	1.33	0.21	0.92	1.11	1.85	2.24	0.51	4.40	2.87	0.21 - 4.40
2. Suspended Solids, wt percent	0.30	0.98	1.03	0.04	0.65	0.55	1.20	1.72	0.20	0.04	5.85	0.04 - 5.85
3. Filterable Residue, wt percent	4.14	0.92	0.30	0.17	0.27	0.56	0.65	0.58	0.31	0.22	6.50	0.17 - 6.50
4. Fixed Residue, wt percent	2.42	0.81	0.55	0.11	0.47	0.41	1.64	0.84	0.26	4.36	5.80	0.11 - 5.80
5. pH	8.0	8.6	8.2	7.0	6.0	6.1	6.6	8.3	8.3	7.6	6.4	6.0 - 8.6
6. Conductivity, µmhos/cm	40,000	26,000	12,000	1,400	4,410	10,800	9,900	9,800	13,000	42,000	----	1,400 - 42,000
7. COD, mg/l	2,576	20,360	16,500	9,900**	24,400	24,400	42,800	38,700	4,680	1,296	102,650	1,296 - 102,650
8. Soluble COD, mg/l	1,240	7,008	3,760	8,900**	1,820	5,440	9,680	2,300	3,600	684	23,600	684 - 23,600
9. Total Chromium, mg/l	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
10. Hexavalent Chromium, mg/l	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
11. Copper, mg/l	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
12. Zinc, mg/l	<1.0	<1.0	<1.0	2.6	34	181	79	28	<1.0	<1.0	8.5	<1.0 - 181
13. Nickel, mg/l	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.01	<0.01 - <0.1
14. Chlorides, mg/l	13,490	4,283	1,100	<2.0	6.0	<2.0	<2.0	<2.0	1,821	11,760	30	<2.0 - 13,490
15. Sulfate, mg/l	860	1,050	2,350	190	1,650	713	710	650	330	1,350	4,125	190 - 4,125
16. Total Phosphorus, mg/l	12	350	220	23	138	164	166	138	1,620	85	1,625	12 - 1,625
17. Total Kjeldahl Nitrogen, mg/l	4,285	8,487	3,956	506	467	2,317	1,803	1,695	2,303	1,804	----	467 - 8,487
18. Total Organic Nitrogen, mg/l	907	100	100	84.2	56.9	325	222	273	3.0	4.1	----	3.0 - 907
19. Total Inorganic Nitrogen, mg/l	3,378	8,500	3,978	421.7	410	1,992	1,581	1,422	2,300	1,930	4,000	410 - 8,500
20. Nitrates-Nitrogen, mg/l	0.5	13.0	22.0	1.7	2.0	12	1.0	22	<1.0	130	<1.0	0.5 - 130
21. Nitrites-Nitrogen, mg/l	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
22. Ammonia Nitrogen, mg/l	3,378	8,487	3,956	420	408	1,980	1,580	1,400	2,300	1,800	4,000	408 - 8,487
23. Anionic Detergents, mg/l	<0.05	2.4	<0.05	30	<0.05	<0.05	3.2	3.0	5.6	<1.0	<0.05	<0.05 - 30
24. Iodine & Iodides, mg/l	0.02	0.02	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02

*NOTE: SAMPLE IV NOT ANALYZED BECAUSE OF EXCESSIVE AMOUNT OF OIL IN SAMPLE.
**NOTE: COD AND SOLUBLE COD VALUES IN SAMPLE V ARE TOO HIGH DUE TO UNEXPLAINED ANALYTICAL ERROR.

generally low, except for higher zinc concentrations detected in samples from marinas on Lake Michigan. The higher zinc concentration is probably caused by zinc sulfate based chemical additives.

SECTION V

SURVEY OF CHEMICAL ADDITIVES

The wastes collected in marine sewage systems will start to decay and produce odorous gases unless the action of microorganisms is controlled by suitable bacteriostatic agents or enzymes. Typical commonly used chemical compounds that exhibit bacteriostatic activity include phenols, quaternary ammonium salts, heavy metals, chlorine, and formaldehyde. GARD tested the representative bacteriostats listed in Table 3 to determine their effect on a Teflon-lined stainless steel vessel. This test was used to verify the corrosion resistance of the evaporator used in the GARD Evaporative Toilet System. A mixture of bacteriostats, wastes, and saltwater was boiled in the vessel for 15 days without any deleterious effects on the wall of the vessel. Also, an 80-gallon, electrically heated evaporator, similar to the gas-heated evaporator used herein, and coated with the same Teflon lining, has been in service onboard the U S. Navy vessel MONOB for one year. This evaporator was used in a saltwater flushing Evaporative Toilet System and has successfully passed a series of U.S. Navy tests with no apparent degradation of the evaporator lining.

Table 3. TYPICAL BACTERIOSTATS USED IN WATERCRAFT WASTE HOLDING TANKS

Classification	Manufacturer	Brand	Principal Active Ingredient
Formaldehyde	Thetford	Aqua-Kem	37% Formaldehyde Solution
Quaternary Ammonium Salt	Consan Pacific	Consan 20	Mixture of Alkyl Dimethyl Ammonium Chlorides
Heavy Metal	Monogram Ind.	Monochem T-5	Zinc Sulfate

SECTION VI

OPERATING CHARACTERISTICS OF AN EVAPORATIVE WASTE TREATMENT SYSTEM

CONCENTRATION

The evaporative waste treatment system is a process to reduce the volume of wastes by boiling off excess water and venting the steam to the atmosphere; the process also destroys microorganisms that would otherwise grow in ambient temperature sewage. Wastes from freshwater watercraft can be concentrated to a solids content of approximately 12 percent by weight whereas wastes from toilets flushed with saltwater can be concentrated to a solids content of approximately 36 percent by weight, the increased percentage being attributable to the salts present in seawater. Concentration behond these values is possible but tends to cause pumpout difficulties when the evaporator is drained and cleaned.

Assuming that the density of the solids is not significantly different than the density of water, the wastes from freshwater vessels can be reduced by a factor of 12, if the incoming wastes contain approximately 1 percent solids. Thus, an evaporator with a 230-l (60-gal.) working volume, or 300 l (80 gal.) total volume, can collect 2700 l (720 gal.) of wastes before the evaporator must be serviced by draining the sludge. Correspondingly, wastes from a saltwater flushed sanitary system can be reduced by a factor of 8, if the incoming wastes contain approximately 4.5 percent solids; saltwater alone contains approximately 3.5 percent dissolved solids. Thus, the same size evaporator can collect 1800 l (480 gal.) of wastes before servicing.

ENERGY REQUIREMENTS

Energy is required for the evaporative process to raise the temperature of the wastes from ambient temperature to 100°C (212°F) and to supply the latent heat to convert the liquid water to steam.

Theoretically, pure water requires 100 kcal/kg (180 Btu/lb) to increase its temperature from 0°C (32°F) to 100°C (212°F) and an additional 538 kcal/kg (970 Btu/lb) of latent heat to convert the liquid to steam for a total of 638 kcal/kg (1150 Btu/lb). Suspended organic solids have very little influence on the boiling point

or the heat required for vaporization; however, dissolved salts such as urea or sodium chloride from urine or salts from seawater-flushed systems will slightly elevate the boiling point and hence the heat required for evaporation of the waste water. Synthetic seawater concentrated by evaporation to approximately 25 percent by weight salts with organic wastes added boils at approximately 110°C (230°F) and requires approximately 642 kcal/kg (1157 Btu/lb) to produce steam from seawater-flushed wastes.

SLUDGE INCINERATION

The sludge produced in the evaporator must be periodically removed after the solids concentration reaches 12 percent or 36 percent for seawater-flushed wastes. This sludge can be further dried by a spray dryer or similar drying equipment capable of handling sludges and used as a landfill, or it can be burned in an incinerator. In order to test a total system, the GARD oil-fired sludge incinerator was tested with sludge from an evaporator. The objectives were to maximize the capacity of the incinerator and to investigate tray materials to increase useful life of the sludge trays.

The incinerator operates on a batch cycle to eliminate feeding sludge to a hot incinerator. The cycle is:

FEED
PREHEAT STACK
INCINERATE
COOL

Periodically, the ash is removed from the cooled tray by a vacuum cleaner attachment.

SECTION VII

EVALUATION OF AN EVAPORATIVE WASTE TREATMENT SYSTEM

A Groen* model HH2-80 gas-fired (propane), steam-jacketed, processing kettle modified to GARD specifications was used to evaporate excess water from sanitary wastes and thereby reduce the volume of wastes by concentration of the sewage.

LABORATORY SET-UP

Full scale tests were conducted with wastes collected from:

(1) In-house washrooms by connecting the building's sewer line to a sump from which wastes were pumped.

(2) A waste disposal company that empties holding tanks from marinas located in inland recreational lakes (Chain-O-Lakes, Illinois area) and construction sites.

Wastes from toilets and washbasins were collected in a sump built into the sewer line in the GARD shop/laboratory building and were drawn from the sump and pumped to the evaporator on demand with a 1.1-kw (1.5-hp) self-priming centrifugal pump, as shown in Figure 1. The steam generated in the evaporator was vented through a 76-mm (3-in.) pipe to a hood in the laboratory. Another 1.1-kw (1.5-hp) centrifugal pump was used to recirculate the wastes in the evaporator for 5 minutes every hour and a valve to draw samples was installed in the recirculation line. This location allowed representative samples of the wastes to be removed from the system for analysis. By recirculating the wastes prior to and during sample collectnon, a uniform sample could be obtained.

The waste mixture from marinas and construction sites was stored in 210-l (55-gal.) drums outside the building. The drums were connected to the sewage pump with a 38-mm (1.5-in.) ID rubber hose.

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* Groen Division, Dover Corporation, Elk Grove Village, Illinois

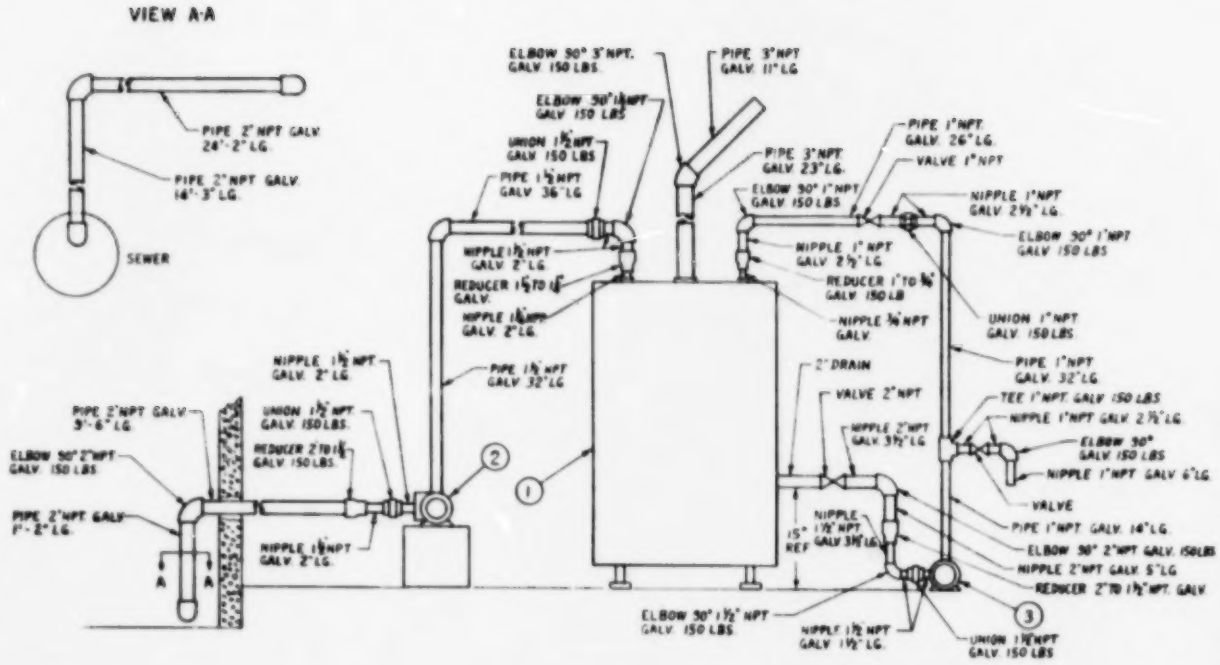
VIEW A-A
PIPE 2" NPT GALV 24'-2" LG.
PIPE 2" NPT GALV 16'-3" LG.
SEWER
ELBOW 90° 3" NPT GALV 150 LBS.
PIPE 3" NPT GALV 11" LG
ELBOW 90° 1½" NPT GALV 150 LBS
UNION 1½" NPT GALV 150 LBS
PIPE 1½" NPT GALV 36" LG
PIPE 3" NPT GALV 23" LG.
PIPE 1" NPT GALV 26" LG.
VALVE 1" NPT
ELBOW 90° 1" NPT GALV 150 LBS
NIPPLE 1" NPT GALV 2½" LG.
ELBOW 90° 1" NPT GALV 150 LBS
NIPPLE 1½" NPT GALV 2" LG.
NIPPLE 1" NPT GALV 2½" LG.
REDUCER 1½ TO 1" GALV.
REDUCER 1" TO ¾" GALV 150 LB
NIPPLE ¾" NPT GALV.
UNION 1" NPT GALV 150 LBS
NIPPLE 1½" NPT GALV 2" LG.
PIPE 1½" NPT GALV 32" LG
2" DRAIN
PIPE 1" NPT GALV 32" LG
VALVE 2" NPT
TEE 1" NPT GALV 150 LBS
NIPPLE 1" NPT GALV 2½" LG.
PIPE 2" NPT GALV 5'-6" LG.
UNION 1½" NPT GALV 150 LBS.
NIPPLE 2" NPT GALV 3½" LG
ELBOW 90° GALV 150 LBS
ELBOW 90° 2" NPT GALV 150 LBS
REDUCER 2" TO 1½" GALV 150 LBS.
NIPPLE 1" NPT GALV 6" LG.
PIPE 2" NPT GALV 1'-2" LG.
VALVE
NIPPLE 1½" NPT GALV 2" LG.
NIPPLE 1½" NPT GALV 3½" LG.
15° REF
PIPE 1" NPT GALV. 14" LG.
ELBOW 90° 2" NPT GALV. 150LBS
NIPPLE 2" NPT GALV. 5" LG
REDUCER 2" TO 1½" NPT. GALV
ELBOW 90° 1½" NPT GALV 150 LBS.
NIPPLE 1½ NPT GALV 1½" LG.
UNION 1½" NPT GALV 150 LBS
A
A
1
2
3

Figure 1. Evaporator Plumbing Layout

LPG (propane) was used to heat the evaporator. The LPG cylinders were stored and connected outside the laboratory building. A supply regulator reduced the pressure to 34 mm Hg (18 in. W.G.). The volume of fuel used was measured with a gas meter while manometers were used to indicate pressures in the supply line and directly before the burner. Exhaust gas was vented to a laboratory hood.

Figure 2 shows the evaporator, recirculation pump, and instrumentation. A wash meter in the rinse water line was used to measure the amount of fill or rinse water added to the evaporator before and after processing wastes. Figure 3 shows the same evaporator but includes a view of the sewage feed pump. This pump has a clog-resistant impeller and has a built-in check valve to prevent back syphoning and to make the pump self-priming.

START UP

Initial shakedown tests using water in the kettle showed that the nameplate firing rate was not achieved and that vigorous boiling produced rapid cycling of the level sensor, which is used to control the gas solenoid valve for the evaporator heaters. The first problem was corrected by changing the gas pressure regulator in the fuel line to increase the fuel delivery from 1.05 m^3/hr (37 ft^3/hr) to 1.44 m^3/hr (51 ft^3/hr). This modification increased the heat input from approximately 23,000 kcal/hr (93,000 Btu/hr) to 32,300 kcal/hr (128,000 Btu/hr). At the same time, the jacket steam gauge pressure increased from 1.3 kg/cm^2 (18 psi) to 2.0 kg/cm^2 (28 psi). The second problem was corrected by adding a time delay relay to the level sensor circuit so that the float level had to remain activated for at least 10 seconds before the gas solenoid valve would be initiated.

After these problems were corrected, the system was connected to the GARD laboratory/shop sewer line as described in "Laboratory Set-Up".

TEST RESULTS

During full scale operation the evaporator was operated only during normal working hours, i.e., 8 hours per day, 5 days per week. These tests were run for 20 operating days. During this time, 3450 l (912 gal.), or 3450 kg (7606 lb), of sewage was fed to the evaporator and 358 kg (790 lb) of LPG were used to evaporate 3227 kg (7114 lb) of water. The observed overall thermal efficiency for the batchwise operation was 47.9 percent. Since the thermal efficiency of a preheated evaporator is approximately 65 percent, the difference is caused by the heat required for preheating the evaporator to its

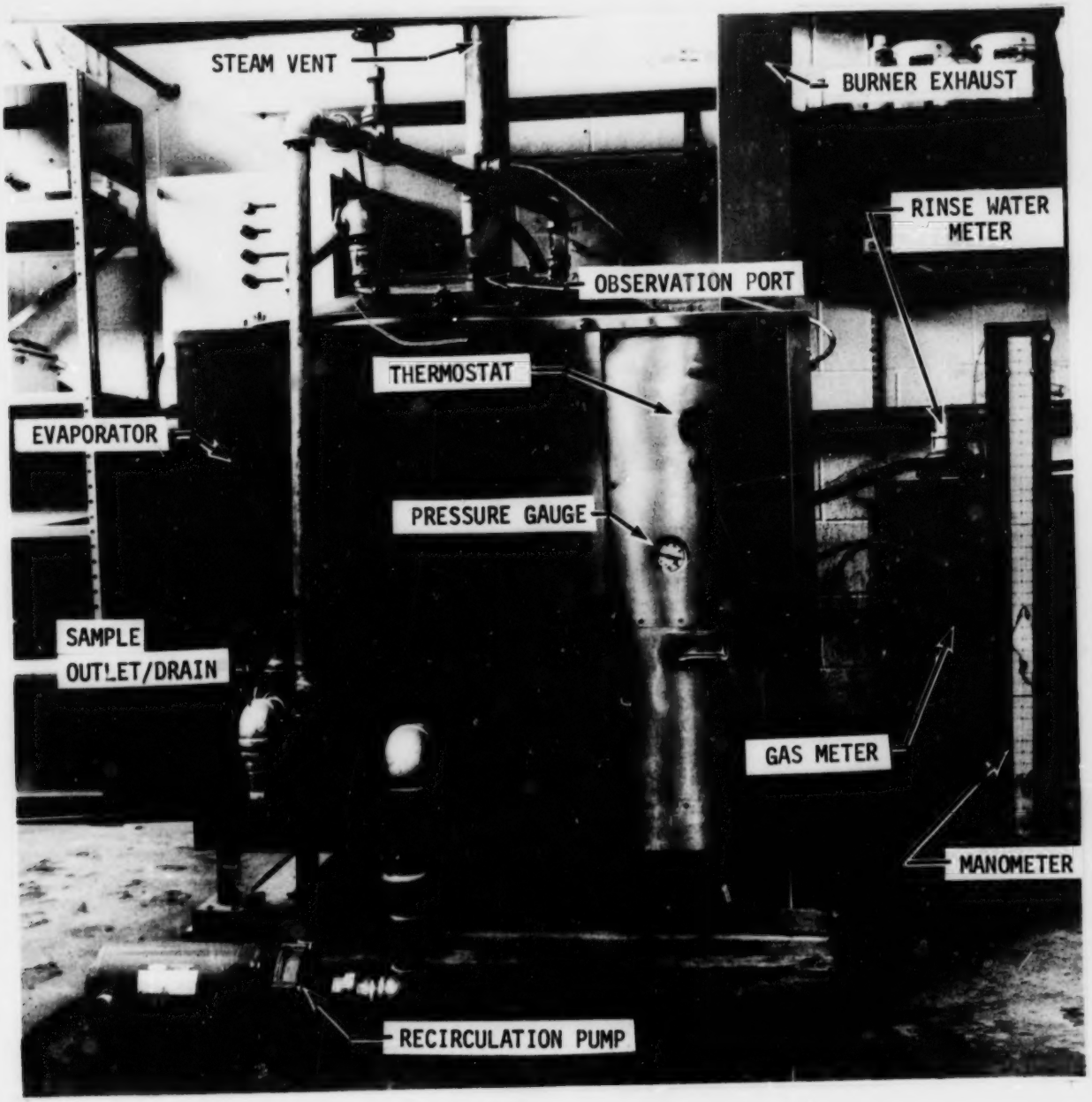

Figure 2. Laboratory Set-Up of Evaporative System

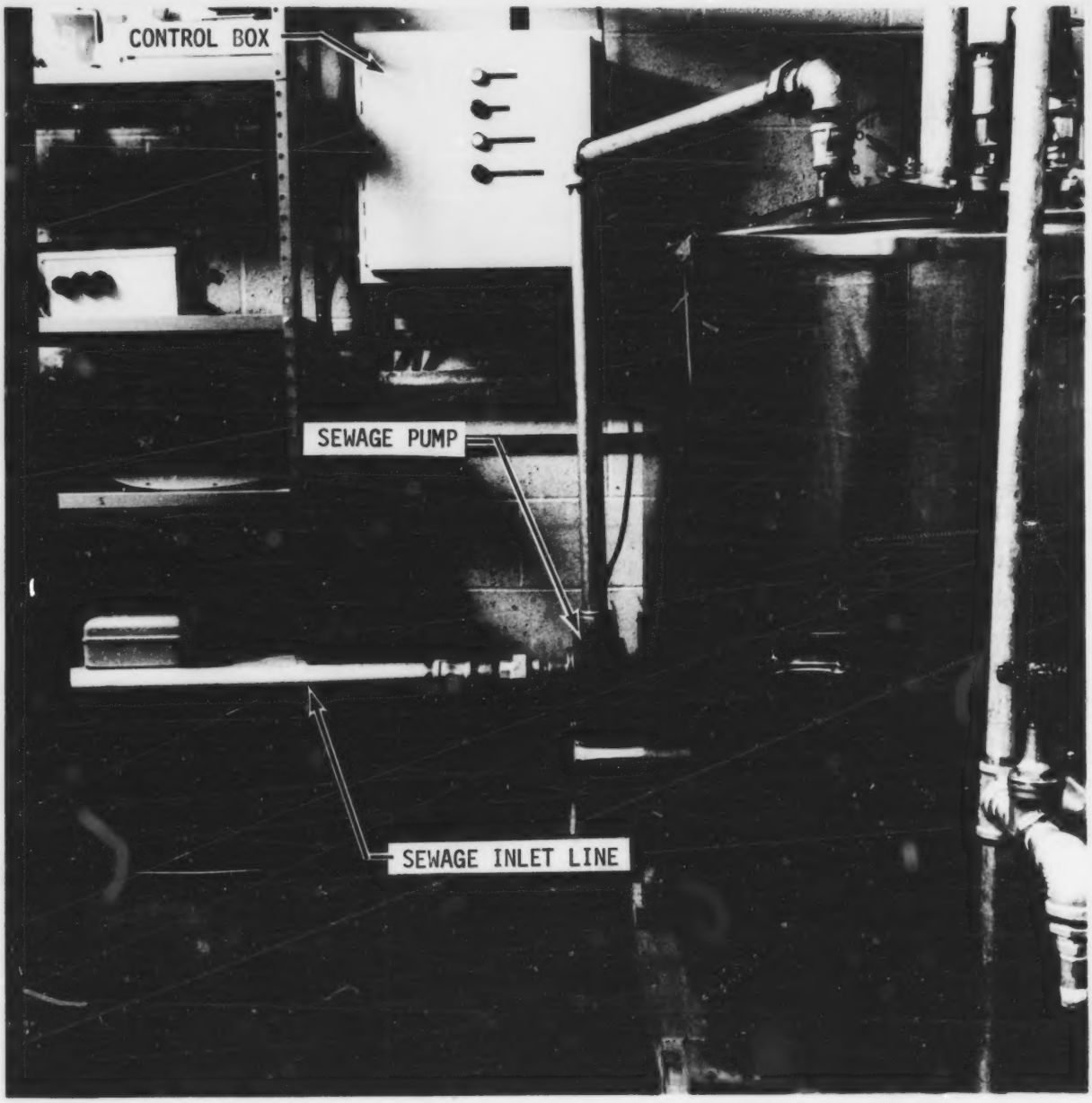

Figure 3. Laboratory Set-Up of Evaporative System Showing Sewage Feed Pump

operating temperature each day. An evaporator operated for continuous processing would, therefore, approach a thermal efficiency of 65 percent.

After the evaporator was run for 20 days with wastes collected from the GARD sewer line, 1140 l (300 gal.) of wastes were obtained in 210-l (55-gal.) drums from a "honeywagon" operator who services the holding tanks from construction sites and marinas located in the Chain-O-Lakes region in northern Illinois. The sludge from tests with in-house wastes was left in the evaporator when this new batch of sewage was added. At this time 170 l (44 gal.) of sludge with total solids concentration of approximately 4 percent by weight remained in the vessel. The steam jacket operating pressure was still approximately 2.25 kg/cm^2 (32 psig), which indicated that the sludge in the vessel was not yet materially impeding the heat transfer from the steam jacket to the wastes. The 1140 l (300 gal.), or 1134 kg (2500 lb) of marina/construction site wastes were fed into the evaporator over a period of eight working days. The reason eight days were required to process this amount of waste was that the waste foamed and the evaporator heater had to be shut off frequently to prevent overflow of the wastes out of the evaporator. A total of 104 kg (229 lb) of LPG (propane) was required to evaporate 1134 kg (2500 lb) of water for an overall thermal efficiency of 58 percent. The average solids concentration of the marina/construction site wastes was 2.84 percent by weight. During the evaporation of water from these wastes, the solids concentration increased from 4.0 percent to 12.4 percent by weight. As expected, this increased solids concentration inside the evaporator impeded the heat transfer from the steam jacket to the wastes within the vessel. Thus, to transfer the same quantity of heat, the pressure in the steam jacket rose from 2.25 kg/cm^2 (32 psig) to 3.09 kg/cm^2 (44 psig).

The 12.4 percent solids sludge in the vessel appeared to be the upper limit for concentrating sewage by evaporation because at this concentration the sludge is so thick that it is difficult to pump, it adheres to the level sensors and interferes with their operation, and it lines the walls of the evaporator and hinders heat transfer from the steam jacket to the wastes. A graph showing the effect of solids concentration on steam jacket pressure is shown in Figure 4.

The results of testing the evaporator with sewage from the GARD sewer line and from marina/construction sites are summarized in Table 4. The physical and chemical properties of the final sludge is summarized in Table 5.

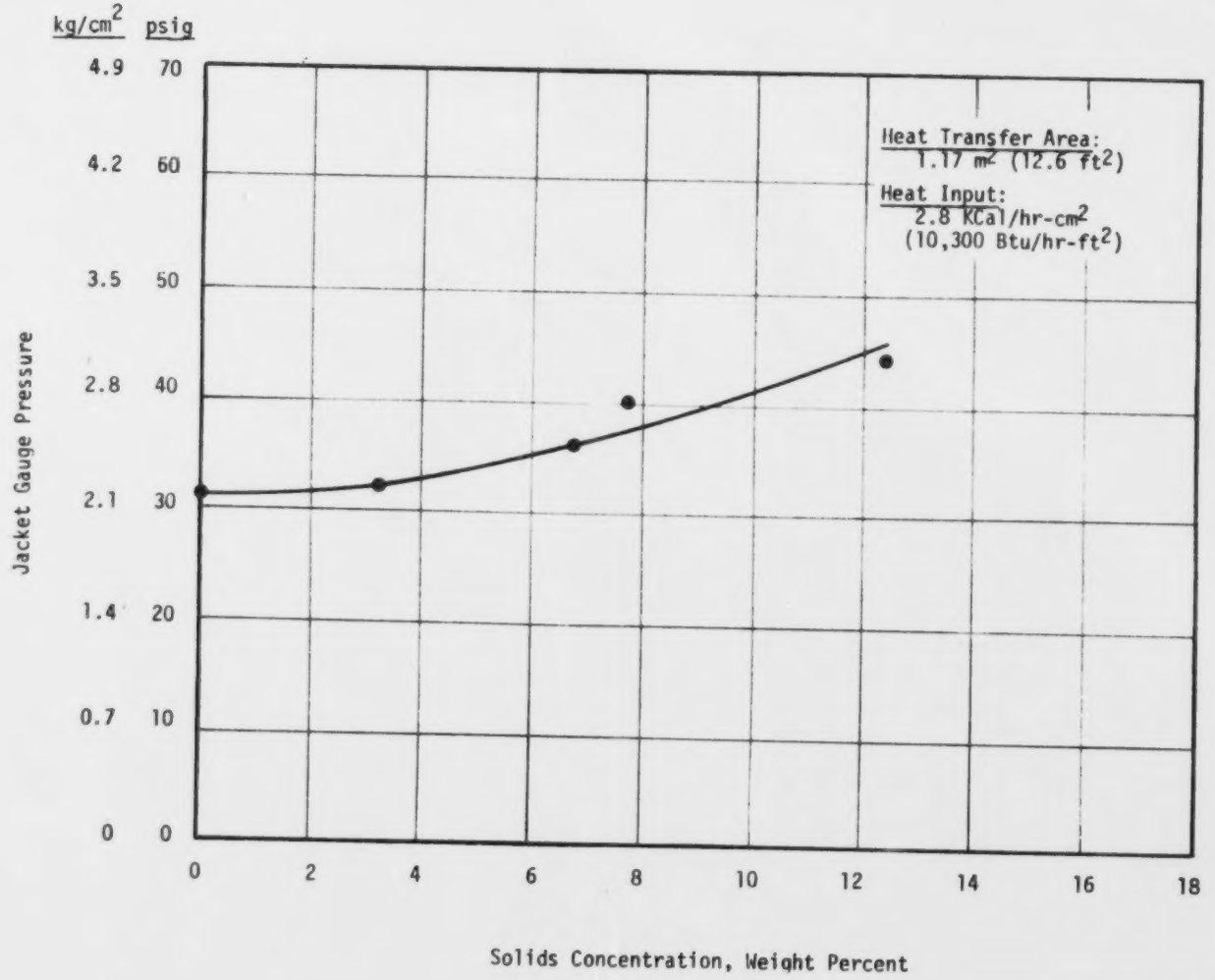

Figure 4. Effect of Solids Concentration on a 300-l (80-gal.) Evaporator

Table 4. SUMMARY OF OPERATION OF EVAPORATOR WITH SEWAGE

Evaporator Capacity:	300 l (80 gal.)
High Level:	250 l (65 gal.)
Operating Level:	160 l (42 gal.)
Tests with In-House Sewage	
Input Solids Concentration:	0.5 percent by weight
Total Input:	3,450 l (912 gal.)
Days Operated:	20
Initial Evaporator Solids Concentration:	0.5 percent by weight
Final Evaporator Solids Concentration:	4.0 percent by weight
LPG Used:	358 kg (790 lb)
Tests with Marina/Construction Site Sewage	
Input Solids Concentration:	2.8 percent by weight
Total Input:	1140 l (300 gal.)
Days Operated:	8
Initial Evaporator Solids Concentration:	4.0 percent by weight
Final Evaporator Solids Concentration:	12.4 percent by weight
LPG Used:	104 kg (229 lb)

Table 5. PROPERTIES OF SLUDGE AT END OF TESTING

Material	Amount Present
Total Solids, wt. percent	12.4
Suspended Solids, wt. percent	5.85
Filterable Residue, wt. percent	6.50
Fixed Residue, wt. percent	5.80
pH	6.4
COD, mg/l	102,650
Soluble COD, mg/l	23,600
Total Chromium, mg/l	<0.06
Hexavalent Chromium, mg/l	<0.06
Copper, mg/l	<0.01
Zinc, mg/l	8.5
Nickel, mg/l	<0.01
Chlorides, mg/l	30
Sulfate, mg/l	4,125
Total Phosphorus, mg/l	1,625
Total Inorganic Nitrogen, mg/l	4,000
Nitrates-Nitrogen, mg/l	<1.0
Nitrites-Nitrogen, mg/l	<0.1
Ammonia Nitrogen, mg/l	4,000
Anionic Detergents, mg/l	<0.05
Iodine-Iodide, mg/l	<0.02

VAPOR EFFLUENT

The vapor effluent of the evaporator has been investigated for

(a) Presence of air pollutants,
(b) Odors, and
(c) Sterility.

A series of analytical tests was performed on the steam effluent from the evaporator. The noncondensable gases mixed in with the steam were analyzed for the presence of specific gases, namely CO_2, CO, H_2S, SO_2, NH_3, and CH_4. In all analyses the noncondensables were separated from the steam by drawing the gas sample through a drying column which removed the steam vapor, leaving only the dry noncondensable gas mixture. A gas chromatograph was used to measure CO_2 and CH_4. A hand-syringe and specific indicator tubes for each gas were used to detect the presence of the other gases. The primary purpose of analysis was to show that common air-pollution contaminants were not present at levels above anticipated pollution control standards. The analysis was not performed to identify possible odor-causing materials. The results of the analysis of the dry noncondensables, and the detection range of the analytical instrument used, are summarized in Table 6. With the exception of CO_2, the concentrations of other noncondensables tested were below the detection limit of the instrument employed. However, the condensate contained varying amounts of NH_3 and hydrocarbons.

The steam effluent from the evaporator exhibits odors of variable levels due to the presence of very small amounts (in the 10 mg/l range and lower) of gases or vapors which have been driven off from feces and urine in the boiling process. These gases and vapors are generated by simple release from the solids due to physical agitation or mechanical break-up in the 100°C (212°F) boiling process, by steam distilling of vapors along with boil-off of water, or by actual chemical decomposition of wastes due to heating. Since the human sense of smell is far more sensitive than many standard analytical instruments, odors can be readily detected even when the concentrations of certain gases or vapors may be too low for a direct analytical detection and identification. In addition, synergistic effects of several odorants present at very low concentrations enhance the recognition of the presence of odor by the human sense of smell.

The odors emanating from the evaporator can be eliminated by a low temperature catalytic vapor treatment system. This treatment consists of mixing the vapor with adequate amounts of air and passing the resultant mixture through a suitable catalyst bed maintained at 177-204°C (350-400°F). This concept of human waste related odor removal was extensively tested for evaporative toilet

Table 6. DETECTION OF TRACE CONTAMINANTS

Gas	Instrument	Detection Range	Amount Present
CO_2	Chromatograph	0.1 - 10%	2%
CH_4	Chromatograph	0.1 - 10%	<0.1%
CO	Syringe & Indicator Tube	10 - 100 ppm	<10 ppm
H_2S	Syringe & Indicator Tube	1 - 800 ppm	<1 ppm
SO_2	Syringe & Indicator Tube	1 - 400 ppm	<1 ppm
NH_3	Syringe & Indicator Tube	10 - 1500 ppm	<10 ppm
NO_2	Syringe & Indicator Tube	0.1 - 50 ppm	<0.1 ppm
Air	(By difference)		~ 98%

systems and found satisfactory in systems operating for periods of more than one year. In particular, a catalytic vapor treatment system was installed on the U.S. Navy vessel MONOB to treat the vapor effluent from the Evaporative Toilet System. The vapor treatment system has successfully passed a series of U.S. Navy tests wherein no objectionable odors or deterioration of the catalyst bed were apparent during the year operated.

During previous programs with evaporative systems, an extensive series of tests were conducted by outside laboratories to measure the sterility of the condensed steam from the ETS evaporator. The tests showed that no live bacteria were present and that the condensate is sterile.

COSTS

The estimated capital cost of an evaporator capable of treating 1900 l (500 gal.) of sewage per day, including basic ancillary equipment such as pumps, piping, electrical and fuel connections, controls, and vapor treatment system, but excluding grounds, buildings, fuel and sewage lines, is approximately $20,000. Operating experience indicates that a system operating continuously reaches 65 percent thermal efficiency; therefore, the thermal energy requirements are 1.0×10^6 kilocalories per 1000 l of sewage (15×10^6 Btu/1000 gal.).

The costs of supplying the required thermal energy will depend on the type of fuel used and its price. Operating costs using different heat energy sources are summarized in Table 7. The costs of electrical power required for pumps, controls, etc., are insignificant and are therefore neglected. Since the solids content constitutes only a small fraction of the total sewage weight, there are no significant differences in energy consumption and operational costs regardless of the type of sewage treated.

PROBLEM AREAS

Two problems reoccurred during the evaporation of sanitary wastes. First, the self-priming centrifugal pump that transports wastes into the evaporator became clogged with extraneous material such as mop strings, paper, and plastic toys, and had to be disassembled approximately once a week to remove this debris. This problem can readily be corrected by replacing this type of pump with a grinder type macerator pump similar to that used by GARD in its marine waste treatment systems.

Table 7. OPERATING COSTS OF EVAPORATIVE WASTE TREATMENT SYSTEM*

Source of Heat Energy	Required per 1000 liters	Unit Cost, $	Operating Costs	
			$/1000 l	$/1000 gal.
LPG	180 lb	0.160	28.8	109.0
Electrical	1161 KWH	0.032	37.2	140.6
Fuel Oil #2	29 gal.	0.279	8.0	30.4
Natural Gas	40 therms	0.076	3.0	11.4

*1974 Dollars

The other problem was foaming of the boiling wastes. The foaming was caused by surfactants introduced to the wastes with chemical toilet additives. Excess foaming caused wastes to spurt out of the vent stack of the evaporator especially when the evaporator was full and there was little ullage space between the top of the wastes in the tank and the inlet to the vent. This problem was partially controlled by adding Dow Corning H-10 Anti-Foam emulsion to the boiling wastes and by lowering the high level sensor to provide more ullage space at the top of the evaporator tank.

Since there is no control over the addition of chemicals to the marina holding tanks, the foaming problem will have to be controlled by constructing the evaporator with sufficient ullage space at the top of the tank and possibly adding antifoam agents.

SECTION VIII

INCINERATION

PRESENT INCINERATOR

The GARD sludge incinerator is designed to incinerate the solids of the sanitary wastes from the Evaporative Toilet System (ETS). This incinerator accepts these solids in the form of a slurry from the evaporator and incinerates them in a continuous batch process. The incinerator process is totally automatic and only needs periodic service in the form of replenishing filled ash bags. The incinerator processes these solids without odor and within air pollution regulations.

The ETS incinerator is shown in Figure 5. The specifications for this incinerator are as follows:

Physical Characteristics	
Weight	160 kg (350 lb)
Height	1,270 mm (50 in.)
Mounting Base	
Width	460 mm (18 in.)
Length	510 mm (20 in.)
Exhaust Stack Diameter	100 mm (4 in.)

Performance Characteristics	
Fuel Type	#2 Diesel or Fuel Oil
Normal Max. Operating Temp.	1094°C (2000°F)
Normal Max. Stack Exit Temp.	316°C (600°F)

The incinerator contains two oil burners for burning wastes. The upper burner preheats the stack and destroys odorous gases leaving the main combustion chamber. The lower burner heats the combustion chamber and burns the wastes held in the tray within this chamber.

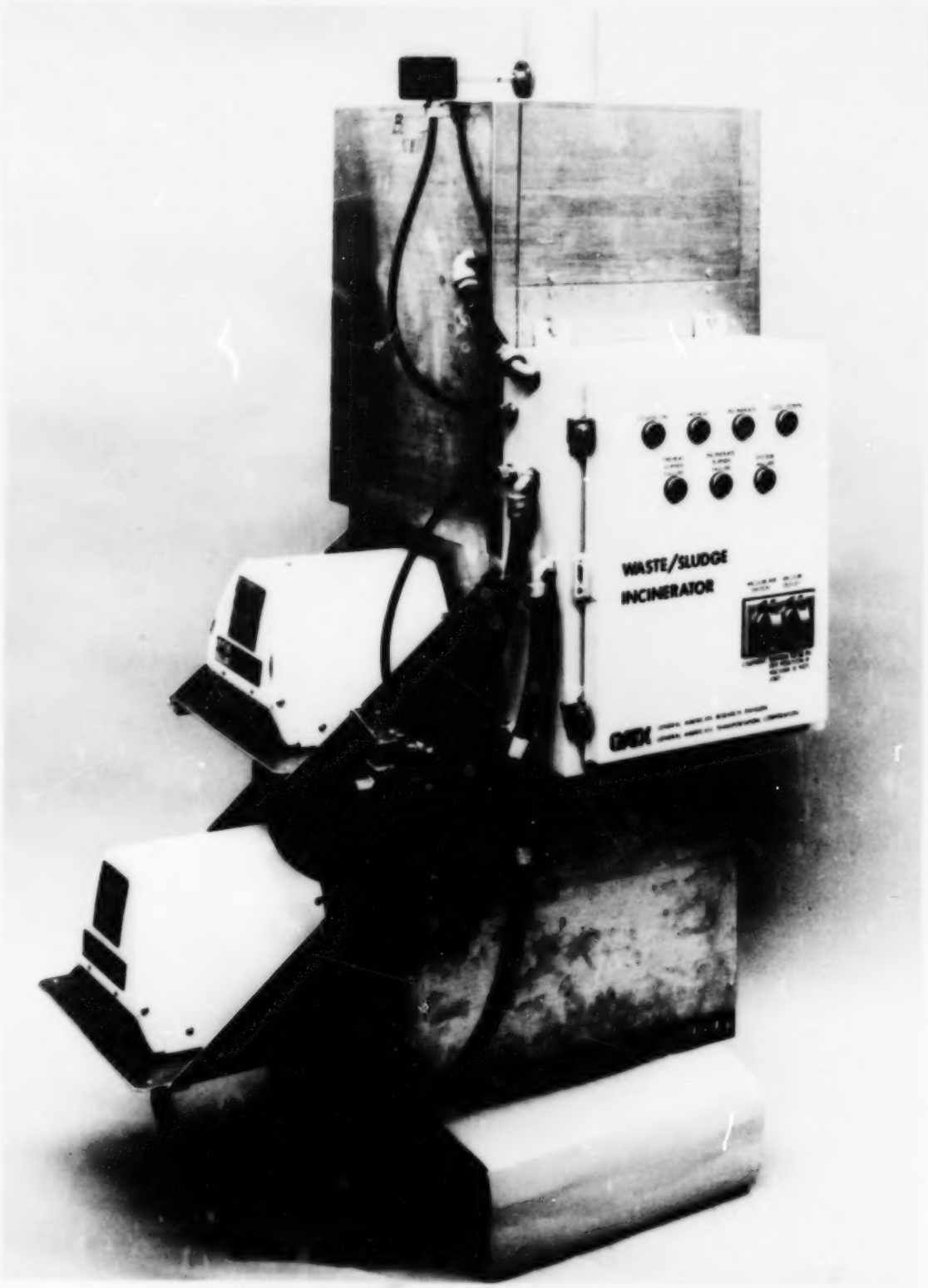

Figure 5. Sludge Incinerator

The incinerator is integrated into the total system, both electrically and physically. The electrical integration is by means of a relay in the control system which senses when the evaporator system has power. Under these conditions, the incinerator will operate simultaneously with the evaporator if required. The incinerator is integrated physically to the bottom of the evaporator plumbing and a feed pump which provides the sludge to the incinerator. This feed pump is tied electrically to the incinerator controls and operates on signal by the incinerator controls whenever a cycle is to begin and a feed is called for. This feed of sludge to the incinerator will take place only when the incinerator is programmed to operate. The incinerator operates on a predetermined time cycle. The completion of one cycle initiates the beginning of the second cycle. The system can operate on as little as one cycle per day or as many continuous cycles as necessary to incinerate all of the accumulated solids. During each cycle, sequential functions take place which include the following:

(1) Feed
(2) Preheat
(3) Sludge Burning
(4) Cool-Down
(5) Ash Removal
(6) Re-Feed and Re-Cycle

Efforts in the development of the marina incinerator were directed to the adaptation of the present GARD ETS incinerator to handle concentrated saltwater and wastes. It appeared that the capacity of the incinerator could be increased to approximately 3 l/hr (0.8 gal./hr) by eliminating the cool-down cycle and adding the sludge to the hot tray immediately following incineration. A further increase in capacity was sought by continuously feeding sludge during the incineration cycle, which results in a dewatering process at a tray temperature of approximately 149°C (300°F). Ultimately, the continuous feeding of sludge would have to be interrupted after a selected period of time (1 or 3 hours) so that the tray temperature can reach 760°C (1,400°F) where incineration of the dewatered sludge will occur.

The addition of salt in the sludge resulted in a crust-type residue after incineration which was very difficult to remove. Different techniques for ash removal at high temperature were investigated. These include thermal shocking of the tray at high temperatures of 760°C (1,400°F) with cold water to dislodge the salt/ash from the tray; the use of screens, rappers, and chains to loosen the ash and scraping the ash from the tray. The most promising of these methods appears to be scraping the ash from the tray with a rake-type scraper. It should be noted that the existing ETS incinerator uses a high-pressure air stream [7 kg/cm^2 (100 psi) gauge] directed at the ash in the tray as a means of ash removal; however, the addition of salt to the sludge causes the ash to adhere to the tray.

In order to increase the capacity of the incinerator, the nozzle for the incinerator burner was changed to increase the burner capacity from 13,000 kcal/hr (50,000 Btu/hr) to 19,000 kcal/hr (75,000 Btu/hr). Tests conducted with the new burner nozzle indicated that the normal incineration time of 20-25 minutes could be reduced to 10 minutes. Direct feeding of the tray immediately after incineration produced a violent reaction, and evolution of a large quantity of steam and spatter. To minimize this reaction, a cool-down period of at least five minutes was required between incineration and feed. The tray temperature after this cool-down period is still approximately 316°C (600°F), so that sizable thermal shock is induced in the tray during the feed period. The effect of this thermal shock or rapid cooling was investigated by conducting endurance tests with cool-down times of five minutes per cycle. The capacity of the incinerator at this rate is approximately 4 l/hr (1.05 gal/hr).

The results of incineration tests using various mixtures of wastes and salt are shown in Table 8. These tests were conducted to determine the maximum amount of saltwater in the wastes that when burned would produce an ash which could be removed from the tray by compressed air. The first five columns listed in Table 8 are representative of the constituents of the waste that might exist at a marina. Column 6 represents these wastes on a per liter basis and Columns 7 through 10 show the results of the incineration of a 1 liter (0.26 gal.) sample of these wastes. The data indicate that a two percent concentration of saltwater in the marina waste, i.e., 19 l (5 gal.) of saltwater in 950 l (250 gal.) of wastes, could be tolerated without the necessity of modifying the normal ash removal technique employed in the standard ETS incinerator. Concentrations of saltwater above two percent would require a scraper to loosen the ash in the tray and an alternate method of removing the ash.

Next in the determination of maximizing the incinerator's capacity, freshwater tests were performed. Incineration tests were begun when the total solids content of the evaporator was low, less than 4 percent and continued until the total solids content was high, greater than 10 percent. The objective of the testing was to determine what was necessary to obtain the desired incineration rate of 4 l/hr (1 gal/hr) of sludge containing 15 percent waste solids or what rates could be obtained without a major modification to the incinerator. To accomplish this, the following was done:

(1) A new two-tier waste tray was designed and fabricated from stainless steel. This tray has a capacity of 2 l (0.5 gal.) and fits within the present chamber. The tray was designed so that the present feed line would fill the top tier and then waste would spill over into the bottom tier.

(2) Tests were run with varying solids content, incineration times, cool-down times, and incinerator burner capacity.

Table 8. SUMMARY OF INCINERATION TESTS WITH SALTWATER-FLUSHED WASTES

1 Saltwater in Evaporator, wt %	2 Volume of Saltwater, l (gal.)	3 Daily Salt Accumulation @ 3% NaCl kg (lb)	4 Total Sludge Accumulation per Day, kg (lb)	5 Salt Concentration in Sludge, wt %	6 Salt Concentration in Sludge, g/l	7 Incineration Time, min.	8 Cooldown Time, min.	9 Max. Temp. Incineration, °C (°F)	Remarks
10	95 (25)	2.9 (6.4)	97 (214)	3.0	30	10	5	1049 (1920)	Contents incinerated; ash remained after air blow; ash requires scraping.
5	47.5 (12.5)	1.4 (3.1)	96 (211)	1.5	15	15	3	1094 (2000)	Contents incinerated; ash remained after air blow.
5	47.5 (12.5)	1.4 (3.1)	96 (211)	1.5	15	10	5	1094 (2000)	Light dust and sparks removed; approximately 95% ash remained.
3	28.5 (7.5)	0.86 (1.9)	95 (210)	0.9	9	12	5	1094 (2000)	Dust and sparks removed; approximately 90% ash remained.
2	19.0 (5.0)	0.59 (1.3)	95 (209)	0.6	6	22	16	1094 (2000)	80% ash removed; remaining ash loose*
2	19.0 (5.0)	0.59 (1.3)	95 (209)	0.6	6	14	6	1094 (2000)	80% ash removed; remaining ash loose*
1	9.5 (2.5)	0.29 (0.64)	94 (208)	0.3	3	10	6	1032 (1890)	95% ash removed; remaining ash loose*
0	0	0	94 (208)	0	0	10	5	1049 (1920)	100% ash removed

*Ash remained in one area of tray due to poorly directed air jet in that area.

The results of testing indicated the following:

(1) At less than 4 percent solids concentration, 4 l (1 gal.) per minute can be incinerated in two 20-minute burn and 10-minute cool-down periods with a 15,000 kcal/hr (60,000 Btu/hr) incineration burner.

(2) At greater than 10 percent solids concentration, the maximum incineration capacity was 1.6 l (0.40 gal.) with 25-minute burn and 10-minute cool-down with a 19,000 kcal/hr (75,000 Btu/hr) nozzle. This amounts to approximately 2.7 l (0.7 gal.) per hour. If a 5-minute cool-down period were used, this would increase to 3.2 l (0.8 gal.) per hour, or approximately 84% of the desired 4 l/hr (1 gal./hr) rate.

Test results indicate that the following cycle is feasible with cast iron trays:

Incineration Function	Time (minutes)
Preheat plenum chamber	15
Fill tray with sludge	<1
Incinerate sludge	30
Cool down tray to 93°C (200°F)	45
Vacuum ash	<1
TOTAL TIME	~90 min. (~1.5 hours)

Based on the above, approximately 1 liter (0.26 gal.) of sludge can be processed per cycle, or 16 l (4 gal.) per day; this amounts to approximately 15 kg (33.4 lb) of sludge per day, or 0.63 kg (1.4 lb) per hour. Assuming that this incinerator is burning sludge containing 12.4 percent pumpable solids, the following expression relates the dependency of the sewage volume per day (R) that can be processed with the present incinerator on the concentration of total solids (S) in the sewage:

$$R\ \frac{\text{gal. sewage}}{\text{day}} = \left(\frac{1\ \text{gal. sewage}}{8.34\ \text{lb sewage}}\right)\left(\frac{.124\ \text{lb solids}}{\text{lb sludge}}\right)\left(\frac{1.4\ \text{lb sludge}}{\text{hr}}\right)\left(\frac{24\ \text{hr}}{\text{day}}\right)/\left(\frac{S\ \text{lb solids}}{\text{lb sewage}}\right)$$

$$R\ \frac{\text{gal. sewage}}{\text{day}} = 0.5/\left(\frac{S\ \text{lb solids}}{\text{lb sewage}}\right)$$

or, in metric equivalents:

$$R' \frac{\text{liter sewage}}{\text{day}} = \left(\frac{\text{liter sewage}}{1000 \text{ g sewage}}\right)\left(\frac{.124 \text{ g solids}}{\text{g sludge}}\right)\left(\frac{.640 \text{ g sludge}}{\text{hr}}\right)\left(\frac{24 \text{ hr}}{\text{day}}\right)/\left(S' \frac{\text{g solids}}{\text{g sewage}}\right)$$

$$R' \frac{\text{liter sewage}}{\text{day}} = 1.9/\left(S' \frac{\text{g solids}}{\text{g sewage}}\right)$$

The above equation, shown graphically in Figure 6, indicates that when the evaporative system module processes 950 l (250 gal.) of sewage per day, the present incinerator is capable of handling all the produced sludge only if the total solids concentration in the sewage does not exceed 0.2 percent, i.e., the lower range of solids encountered in the waste characterization studies. Similarly, if the total solids concentration is 4.4 percent, i.e., the upper limit encountered in the studies, then the capacity of the present incinerator would limit the sewage processing to 43 l (11.4 gal.) per day.

The examples are presented to show that the incinerator capacity limits the performance characteristics of the entire system. It should be noted that the evaporator performance characteristics are sufficient to meet the design goal of evaporating 950 l (250 gal.) ; however, the low capacity of the incinerator prevents the operation of the entire system at the design capacity.

WASTE RECEPTACLE TRAY

The item that failed most frequently in the incinerator was the tray that contains the wastes in the combustion chamber. The environment cycles from hot [1094°C (2000°F)] to cool [93°C (200°F)] and from an oxidizing to reducing atmosphere. Also, the salts present in the wastes further contribute to short tray life. Figure 7 shows a nickel-coated carbon steel tray before and after approximately 30 cycles, and Figure 8 shows the disintegration of an Inconel 625 tray. Gray cast iron trays withstood the corrosive environment better than other trays because of the heavier wall thickness [6.3 mm (0.25 in.) versus 1.6 mm (0.06 in.)]. Table 9 shows a comparison of various tray materials. The incinerator was operated with the thick cast iron waste tray until 160 cycles were obtained. The tray showed some evidence of corrosion, but it appeared that many more cycles could be obtained.

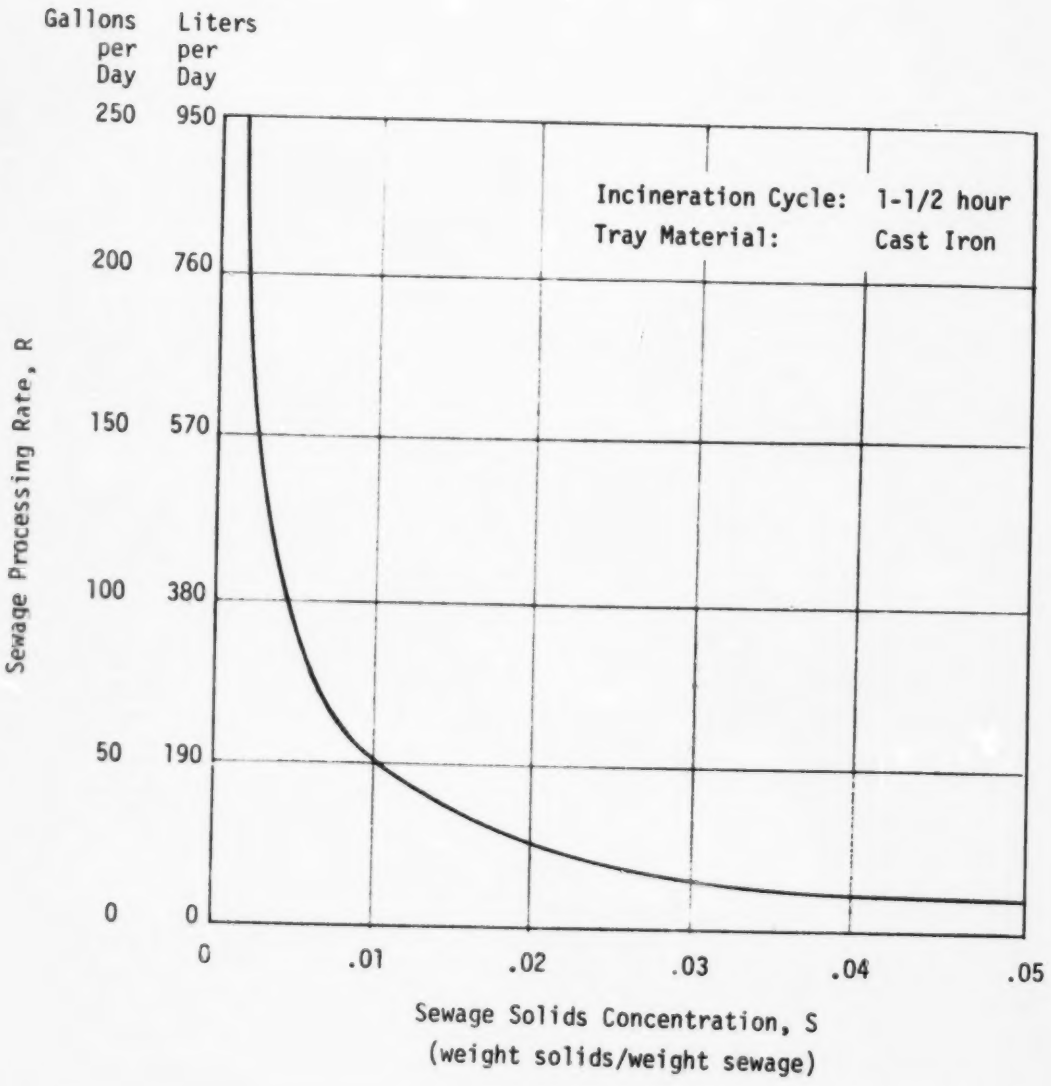

Figure 6. Dependency of Sewage Processing Rate on Solids Content Using Present Incinerator

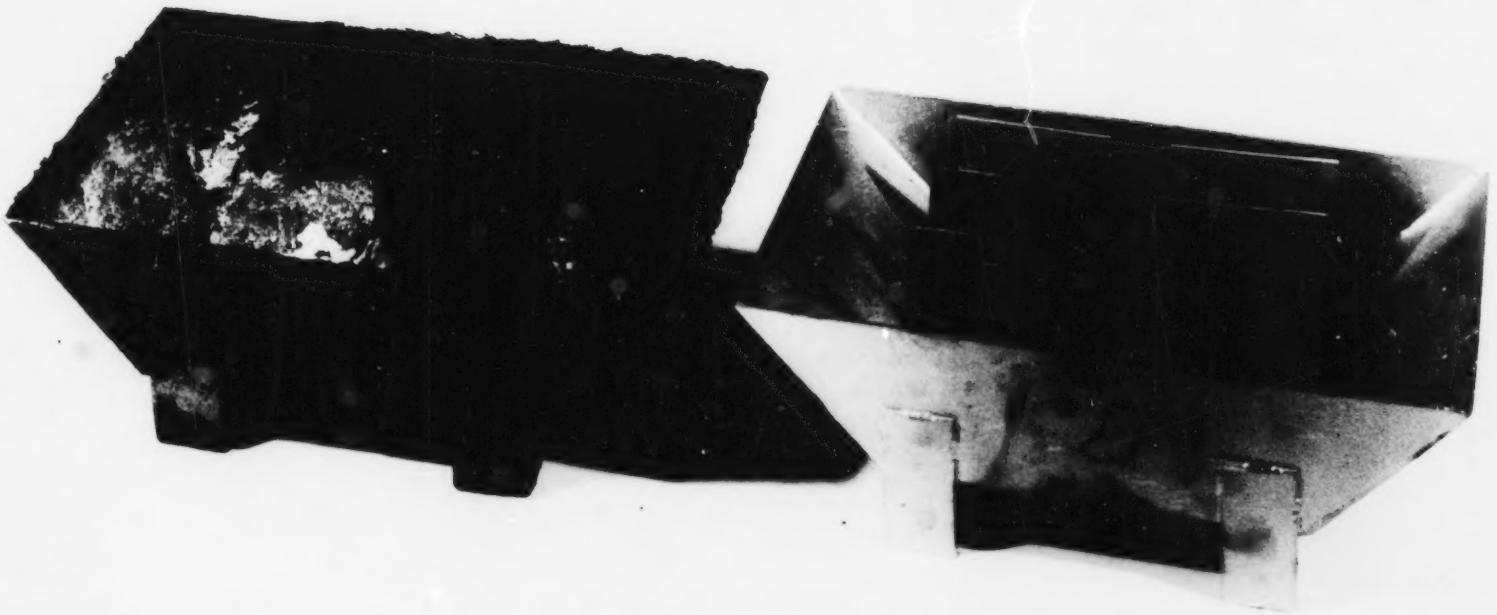

Figure 7. Nickel Coated Steel Tray Before and After Testing

Figure 8. Disintegration of an Inconel 625 Tray

Table 9. TRAY MATERIALS TESTED

Type	Qualitative Results	Number of Useful Cycles
Carbon Steel	No Good	30
Aluminum Oxide Coated Carbon Steel	No Good	30
Nickel Coated Carbon Steel	No Good	30
316 Stainless Steel	Fair	50 to 100
304 Stainless Steel	Fair	50 to 100
Inconel 617	Better	200
Inconel 625	Better	250
Gray & High Alloy Cast Iron	Good	---
Titanium	No Good	30

APPENDIX

ANALYTICAL PROCEDURES

OUTLINE OF ANALYTICAL PROCEDURES

1. Total Solids: Standard Methods for the Examination of Water and Wastewater, 13th Ed., Section 148-A.
2. Suspended Solids: Standard Methods, 13th Ed., Section 148-B.
3. Filterable Residue: Dissolved Solids = Total Solids - Suspended Solids
4. Fixed Residue: Standard Methods, 13th Ed., Section 148-D.
5. pH: Beckman pH meter.
6. Conductivity: Conductivity Bridge Model RC-16B2, Industrial Instruments, Inc.
7. Total COD: Standard Methods, 13th Ed., Section 220.
8. Soluble COD: Sample filtered through a 0.22-micron Millipore filter and the COD performed according to Standard Methods, 13th Ed., Section 220.
9. Total Chromium: Alkaline hypobromite oxidation modification of 1,5-diphenylcarbohydrazide method, Standard Methods, 13th Ed., page 126.
10. Hexavalent Chromium: (See item 9)
11. Copper: Bisuinoline Method, Colorimetric Procedures and Chemical Lists for Water and Wastewater Analyses, Hach Chemical Company, 3rd Ed., 1969.
12. Zinc: Zincon Method, Standard Methods, 13th Ed., page 260.
13. Nickel: Heptoxime method, Standard Methods, 13th Ed., page 443.
14. Chlorides: Mercuric Nitrate Method, Standard Methods, 13th Ed., page 97.
15. Sulfate: Turbidimetric Method, Standard Methods, 13th Ed., page 291.
16. Total Phosphorus: Persulfate Digestion Method, Standard Methods, 13th Ed., page 527.
17. Total Kjeldahl Nitrogen: Standard Methods, 13th Ed., page 469.

OUTLINE OF ANALYTICAL PROCEDURES (Concluded)

18.	Total Organic Nitrogen:	Standard Methods, 13th Ed., page 469.
19.	Total Inorganic Nitrogen:	Sum of Nitrates Nitrogen, Nitrites Nitrogen and Ammonia Nitrogen.
20.	Nitrates-Nitrogen:	Cadmium Reduction Method, Standard Methods, 12th Ed., page 395.
31.	Nitrites-Nitrogen:	Diazotization Method, Standard Methods, 12th Ed., page 400.
22.	Ammonia Nitrogen:	Phenol, Sodium Nitroprusside Method, Microchemical Journal, 9, 166-183 (1965).
23.	Anionic Detergents:	Crystal Violet Method, Standard Methods, 12th Ed., page 291.
24.	Iodine & Iodide:	Black-Whittle Method, Journal of the American Water Works Association, 59, 471 (1967).